A Survey of Camera Modules for CubeSats - Design of Imaging Payload of ICUBE-1

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***Abstract*— ICUBE-1, the first pico-satellite of the space program ICUBE (Institute of Space Technology Pakistan cubeSat program), is set to be launched in the second quarter of 2013 as a part of the international cubeSat program [1]. One of the objects of ICUBE-1 is to get the students familiarized with the satellite imaging system involving image capture, image analysis, compression, storage and retrieval. The objective is not to get high resolution earth images, but to take low resolution images, store them and successfully send them to ground station. A low resolution camera with low power consumption can be mounted on the satellite to achieve the desired objective. Due to mass and power constraints, communication bandwidth limitations and the passive nature of ICUBE-1 attitude control, the choice of cameras rests very limited. This communication presents a detailed survey of the imaging payloads in general and camera modules in particular, providing guidelines for future miniature satellite developers in choosing a camera module and designing their imaging payloads. The paper will describe the purpose of an imaging payload in miniature satellites, different imaging technologies like CCD & CMOS, camera unit and its interfaces. It will also compare the resolution, power consumption and field of views of different cameras used in miniature satellites and in the end, will also propose a camera module best suited for ICUBE-1.**

Keywords—cubeSat, Imaging subsystem, CMOS and CCD imaging sensors

I. INTRODUCTION

CubeSat is a pico-satellite standard designed mainly for gaining invaluable experience on satellite development as well as space research application. The smallest cubeSat 1U has a volume of 10 cubic cm and weighs no more than 1.33 kg [2]. The cubeSat project was initiated by California Polytechnic State University and Stanford University in 1999 in which they developed the cubeSat specifications with the goal of helping the universities worldwide to perform space science and exploration in a cost effective way [2]. After that first cubeSat, several other organizations have also built various cubeSat based missions including some of the major companies like Boeing and NASA [2]. However, majority of development comes from academia, with a mixed record of successfully orbited cubeSats and failed missions mainly due to launch failures [2].

A cubeSat like other spacecrafts can be divided into multiple smaller subsystems including Power, Communication, On board data handling, Attitude determination & control as well as a satellite payload subsystem. Payload determines the actual mission and objective of the cubeSat. Most cubeSats carry one or two scientific instruments as their mission payload. External fuel when optionally carried is also considered a part of payload [2]. Camera can also be used as a payload for taking images that can be used for different applications. There are many types of cameras that can be used in a cubeSat depending mainly on the application it is to be used for. These applications may include weather forecasting, spying missions, surveillance systems etc. However due to mass, power and bandwidth constraints small low resolution CCD or CMOS cameras are generally used in cubeSats which do not give us very high resolutions images.

A few commercial off the shelf cameras are available that can be used in a cubeSat. A particular imaging sensor needs to be selected depending on the constraints at hand as well as the mission requirement. In this survey we try to locate such cameras from various manufactures and compare their traits for recommending the optimal solutions for different imaging applications. We start the paper by giving a general comparison between CCD and CMOS imaging sensors. It will be followed by the detailed description of different small size low resolution cameras and it the end we give the comparison of the cameras and our conclusions.

II. CCD VS CMOS

Small sized low resolution CCD or CMOS imaging sensors and camera modules are generally used in cubeSats for imaging applications. Both the types of cameras have their pros and cons. For example, it has been observed that CCD sensors generally consume more power as compared to CMOS cameras. Similarly, data retrieval mechanism differs in CCD and CMOS. Data can be fetched quicker in CCD but that data is more prone to errors. On the other hand, CCD technology is more mature than CMOS which is still an evolving technique. There is no hard and fast rule which technology is better suited for space missions; however certain parameters need to be kept in mind while selecting a camera. These are the reliability of the imaging module, the resolution of the camera and also

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the speed at which the image is taken. In cubeSats however, the trend is more towards CMOS as they consume less power and can be used for longer time in space as our requirement is to use the camera in cubeSat in space [3].

III. COMMERCIAL CAMERA MODULES

Here we will briefly discuss various cameras that have either been used in some cubeSat or have the potential to be used in future cubeSats. We will list the advantages and disadvantages of these camera units according to mission requirements. This might help future cubeSat developers in selecting a camera for their mission.

A. IDS UI- 1646LE USB 1.3 Megapixel

IDS UI- 1646LE USB 1.3 Megapixel colored CMOS camera is robust, compact and industry proven camera designed by uEye industrial camera family [4]. With the help of USB 2.0 interface, this camera can easily be mounted to wide range of systems with no interfacing issues. USB uEye LE is an extremely compact series of cameras well suited for cost sensitive applications. This camera has already been used in MCUBED cubeSat project [5], which is a 1U cubeSat project initiated by small group of students from Michigan State University, USA. The key objective of MCUBED project was to capture high resolution color images of earth from LEO [5]. To achieve the objective, imaging payload subsystem consisted of this camera and as well as a plano-convex lens which is rigidly mounted inside cubeSat whose focal length is adjusted in such a way that it gives earth resolution of 200-meter per pixel. 1646LE CMOS camera is a board level camera that supports the use of M12 S-mount lenses and gives the resolution of 1280 by 1024 array with the capability of 25 frames per second. Camera takes the image and then saves it into Colibri PXA270 microprocessor. Each pixel is of 8-bits. The image is then compressed by the factor of 10 using JPEG compression algorithms before transmittal to ground. It has a pixel size of 3.6 µm×3.6µm.

This camera is powered by both on-board small Polymer Li-ION batteries and solar arrays placed on every side of cubeSat. A microcontroller processes these images and then sends them to telemetry system for its transmittal to ground station. MCUBED orbit is controlled by passive altitude control system and its orientation is specified with respect to earth's magnetic field.

Fig. 1. IDS UI- 1646LE USB 1.3 Megapixel

B. C3188A

C3188A is a small sized 1/3 color camera module providing digital output. This camera module is comprised of CMOS image sensor OV7620. It can be used for good quality video and still image applications. The digital video port supplies a continuous 8/16 bit-wide image data stream. All the necessary camera functions like gamma correction, exposure, gain, white balance, color matrix and windowing can be programmed through I2C interface by writing into simple registers [6]. This camera can also be interfaced with PC based applications by using OV511+ USB controller chip. The video output can be expressed in different formats like RGB, YCbCr and GRB. C3188a camera module is most commonly used in Video conferencing, PC multimedia, Machine Vision and Still and Video image based embedded applications. It has a pixel size of 7.6 µm×7.6 µm [7].

This camera has been used in ITU-pSAT-1 which is a first student-designed pico-satellite of Turkey launched in November 2009 [8]. The satellite carried two experimental payloads; a low resolution camera with on-board image pre-processing and passive magnetic stabilization with a magnetic rod accompanied by a sensor board to examine its performance. The main objective of this project was to test a CMOS imager and obtain the information on the passive magnetic stability of their satellite attitude through sensing hardware [8]. To achieve the objective, imaging payload subsystem consisted of C3188A low resolution CMOS camera. It consumed very less power. This camera has also been used in Tokyo University cubeSat X1-IV. We tried this camera for ICUBE-1 but faced certain interfacing and synchronization issues that decreased the reliability of the imaging subsystem.

Fig. 2. C3188A Camera Module

C. MCM20027

MCM20027 is manufactured by KODAK. It is a CMOS image sensor that gives good performance. It has got many other features as well like timing control and analog to digital conversion [9]. This sensor is low cost and consumes less power. It can be used in many applications like security applications and fast motion imaging applications [8]. Windowing can be done in this camera and we can use window of our own interest in it.

This sensor was first selected for ICUBE-1 but the issue was to designing and development of an imaging board for the sensor where a separate microcontroller needed to interfaced with this sensor. It couldn't be used directly with the MSP430 microcontroller embedded on the ICUBE-1. It has a pixel size of 6μm×6μm [9].

This camera has been used in AAUSAT which was a student satellite project at the University of Aalborg, Denmark [10]. The mission objective was to establish a communication link with the cubeSat. The camera on the cubeSat was only turned on during capturing the image. The images were always taken in full resolution. The thumbnails were supposed to be downloaded to ground station so that the parameters could be configured [10]. Unfortunately, due to a fault with the transmitter, no images were retrieved from the satellite and the performance of the camera remains unknown [10].

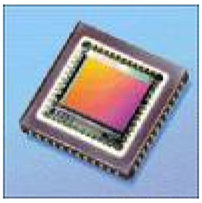

Fig. 3. MCM20027 sensor

D. *PC67XC-2 CCD Color Camera*

PC67XC-2 CCD Color Camera has been developed by the company super circuits. It has a description of 1/3” interline Transfer color code CCD. It has 512(H) x 492(V) PAL pixels. It has total number of 330 lines. It has the luminance of 1.5 Lux. The lens in the camera is 12mm. It requires the DC voltage of 12V [11]. This camera was also used by the Norwegian satellite nCube-1 and nCube-2. These two satellites were built at different universities and colleges in Norway. The main aim of launching these satellites was to explore space and to increase the sense of competition between different universities in the world. The second objective of these satellites was to communicate with the ground station and to test the space-born receiver for tracking ships [12]. But unfortunately the secondary goal was not achieved [12].

Fig. 4. PC67XC-2 CCD Color Camera

E. *MicroCAM TTL*

μCAM is a family of special integrated serial camera modules designed for very compact embedded imaging applications. This camera module consists of an OmniVision CMOS colored sensor, built-in lens, and JPEG compression chip with the capability of utilizing very low power. Also this μCAM camera module is equipped with the serial interface (TTL or RS-232) for ensuring direct serial communication with any host microcontroller via UART or any PC COM port based solutions. This camera can send low resolution (160x120 or 80x60) raw images for viewing or selecting desired images and high resolution (640x480 or 320x240) JPEG images by simple user commands. It has a pixel size of 5.6 μm×5.6μm [13].

Fig. 5. MicroCAM TTL

F. *PB-MV 40*

The PB-MV40 is a world’s fastest 4 megapixel (2352H x 1728V) CMOS digital image sensor capable of capturing 240 frames per second (fps) with the chip input rate of 66MHz at full resolution. It has an on-chip 10 bit A/D converter which is self calibrating and provides an easy to use digital output interface. It is available in both monochrome and color formats. This sensor has 16 (10-bits wide) column-parallel digital output ports that allow the array of 2,352 ADCs simultaneously to digitize the analog data from an entire pixel row. It is an open architecture with the capability to modify its internal operations according to user needs. It has a pixel size of 7 μm×7 μm. It operates at the voltage of 3.3V. Though it has on-chip timing and control circuitry to control most of the pixels, but it still requires a controller particularly FPGA, ASIC or CPLDs to guide the proper sequence of operation. Also, this sensor utilizes the electronic rolling shutter (ERS) to control the sensor’s integration time [14].

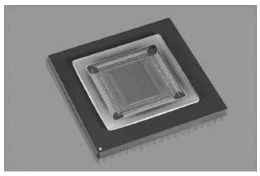

Fig. 6. PB-MV imaging sensor

G. *PB-MV 13*

PB-MV13 is a fast CMOS image sensor. It has the capability to stop the fast running scene with crystal clear image [15]. It has a pixel size of 12 μm×12 μm. It gives 10-bit color or monochrome digital images with a 1.3 megapixel resolution at over 500 frames per second [14]. This sensor is used in high speed image applications. We can also reduce the size of the window and run the sensor on higher frame rate. It has simple digital interface that enable it to control the noise, time, frame rate and many other parameters. If we compare this CMOS based sensor with CCD based sensors, it is easy to design. It is low cost and the power consumption is also very low [15].

H. *OV7648FB Imaging Sensor*

The OV7648FB is a CMOS sensor on-board camera and lens module. It has been specifically designed for mobile applications.. It has a small size and uses very less power [16]. It has a pixel size of 5.6 µm×5.6µm. All required camera functions in it are programmable through the serial SCCB interface. The device can be programmed to provide image output in various fully processed and encoded formats [16]. This camera was used in COMPASS-1 which was a cubeSat developed by Achen University of applied science, Germany and launched on 28th April, 2008. Its purpose was to take pictures of the earth from the unique point of view of a satellite in orbit [17].

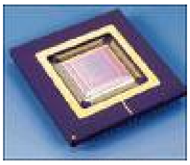

Fig. 7. PB-MV13 imaging sensor

I. HDCS-2020

HDCS-2020 is a CMOS sensor with high resolution and consumes less power. This sensor is used for a number of different applications. It is available in two different forms i.e. either VGA or CIF. It has a pixel size of 7.4µm × 7.4µm. It has been designed for low-cost electronic applications [18]. This sensor has been used by University of Toronto in their satellite CAN-X1 which is a cubeSat developed by students of the University of Toronto. The objective of CAN-X1 project was to verify the functionality of several technologies in orbital space [17]. This cubeSat carried two high resolution cameras onboard which were used in space borne applications and also to take the images of earth and moon [17].

Fig. 8. HDCS-2020 imaging sensor

Brief description and mission history of various cameras has been discussed. Each camera unit has certain pros and cons and the selection totally depends on the mission requirement. In the next section, we have tried to quantify the performance of these cameras for cubeSat applications.

IV. CAMERA COMPARISON

Each camera has been rated for different criteria. The rating varies from --- as the least rating to +++ as the best. The criteria have also been weighted after considering their importance to the project ICUBE-1.

Comparing different cameras, Microcam TTL is gives the optimal solution overall for cubeSat applications. Though this camera has never been used in any cubeSat mission so far, but this camera is of particularly interest for our ICUBE-1 because of its low cost, low power and inbuilt compression capabilities. Apart from that, this camera module can directly be interfaced with any host controller, particularly MSP430 in our case, so we are not worried about choosing any particular dedicated microcontroller for controlling neither a camera's operations nor its PCB designing to mount it onto the main board. The aim of ICUBE-1 project is to take low resolution images that can be compressed and sent it to ground station during the satellite pass. ICUBE-1 will be at an altitude approximately 700km above the earth surface. If we will use the lens of focal length 6mm, the pixel will transform into ground area of 653m×653m by using the triangle formulae as in equation (1). This is depicted in figure 9.

$$\frac{6mm}{5.6\mu m} = \frac{700km}{x} \qquad (1)$$

x=653m

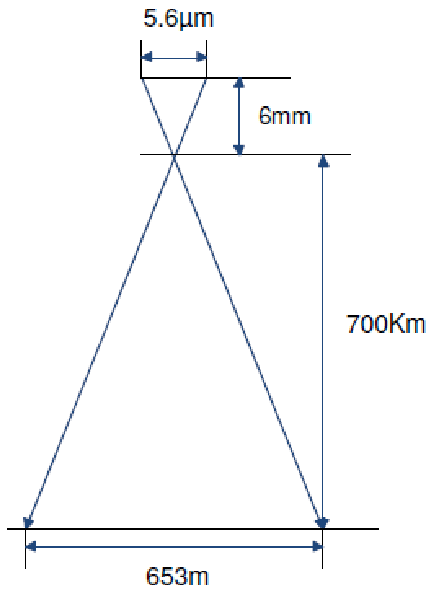

Fig. 9. Calculating Spatial resolution for microCam TTL

V. CONCLUSION

This communication presented a brief survey of various commercial off the shelf options for imaging sensors for cubeSat missions. Quantitative approximation has also been done to analyze various performance metrics of cameras. The overall optimal solution is provided by the microCam TTL. The camera has been interfaced and successfully tested by our ICUBE-1 team as well. For a small price, this camera gives an excellent solution to cubeSat developer interested in employing an imaging payload. The built-in compression module is extremely effective as well. This camera has not been used in any cubeSat yet and it looks like it will be its first flight in Space.

TABLE I. CAMERA COMPARISON: A) IDS UI- 1646LE B) C3188A C) MCM20027 D) PC67XC-2 CCD E) MICROCAM TTL F) PB-MV13 G) PB-MV40 H) OV7648FB I) HDCS-2020

Camera	a	b	c	d	e	f	g	h	i
Power consumption	--	++	++	---	++	++	+	+++	++
Resolution	++	+	--	-	++	--	+	+	+
Price	--	++	+++	-	++	---	---	+	-
Size	+	+	+	++	+	+	+	+	+
Weight	+	+	+	++	+	+	+	+	+
Availability	+	+	+++	+	++	+	+	++	++
Interface	-	---	+	-	+++	-	-	+	+
Voltage level	-	-	++	---	++	+++	+++	++	++
Temperature range	+	+	+	-	+++	++	++	+	++
Space History	+	++	+	+	--	+	+	+	+
Data Acquisition Speed	-	+	+	--	++	+++	+++	++	+
Compression	-	-	-	-	+++	-	-	-	-
Total	**-1**	**7**	**13**	**-7**	**21**	**7**	**9**	**15**	**12**

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